Risk-Based System Safety versus Regulatory Compliance for Management of Occupational Safety and Health Hazards in Military Systems

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Abstract

Several categories of occupational safety and health hazards, nominally under jurisdiction of OSHA regulations, have often been inconsistently addressed in defense acquisition programs. These include control of falls from elevated work locations (the second most common source of occupational fatalities); noise associated hearing loss (the most common occupational medical problem and a special concern within defense systems) and control of physical and atmospheric hazards within confined spaces. Several physical agent hazards are addressed by OSHA standards in only a limited way, through the general duty clause, and often are neglected in design of defense systems and support processes. Major categories include whole body and segmental vibration, ergonomic stressors of posture, repetitive motion and excessive forces. The scope and types of risks these hazards present to personnel, life cycle costs and personnel/system performances are outlined in this and four accompanying papers. Recommendations for the application of system safety approaches to management of these hazards are presented.

Introduction

The discipline of system safety is asked to address an increasingly broad range of risk factors, including many traditionally addressed by industrial safety and/or occupational safety and health regulations. This poses challenges in both technology and outlook. Most safety engineers, managers and industrial workers can cite examples of overly zealous regulators or safety "professionals" enforcing requirements without reference to cost, practicality or integration into mission planning. It also raises the specter of using protective equipment, training and awkward administrative procedures to "control" design hazards. Limiting systems design to the criteria imposed by current regulations is likely to omit considerations of risks that are incompletely addressed by such standards. For example, many current OSHA Permissible Exposure Limits (PELs) for chemical substances are derivatives of 1969 consensus standards. Reliance only upon current, often-outdated standards may stimulate designs and risk management approaches focused on lagging rather than leading, predictive indicators. Additionally, practitioners who are technically limited in the knowledge and "comfort" to address newer methodologies or unfamiliar subject matters may not effectively identify or manage relevant risk factors. Concurrent DOD streamlining and related human resource limitations may increase the risk of such omissions.

This paper and associated presentations by experts in identification and management of common physical agent hazards (noise, whole body and segmental vibration) and ergonomics/human factors engineering are intended to explore current regulatory approaches, help identify common risk factors and promote application of system safety methodology that controls risk factors in systems and equipment design to areas commonly associated with defense systems and equipment.

Regulatory Approaches to Management of Occupational Health and Safety Hazards

System safety as a nationally recognized management approach originated almost concurrently with national regulation of occupational health and safety hazards at work [Ref 1]. The Air Force System Safety Handbook [Ref 2] describes the process (Para 1.5-1.6) as a grass roots movement introduced in the 1940s, with establishment as a formal discipline in the 1960s and formalized incorporation into the acquisition process in the 1970s with development and endorsement of Military Standard 882A in 1969. OSHA regulations were developed following public outrage at several well-publicized disasters with high mortality, publication of statistics estimating the extent of occupational illness and a general rise in occupational injury rates. At the time of the agency's creation it was generally acknowledged that most U.S. states had failed to meet their obligation to provide effective regulation of occupational safety and health; approximately 14,200 employees were killed annually; 2.2 million suffered disabling injuries and injury rates had been rising in most industries throughout the 1960's. [Ref 3]

OSHA has been plagued with institutional obstructions and court challenges that often delay attempts to issue current occupational exposure criteria and rules that are technically up-to-date. The best known of these is the struggle to update Permissible Exposure Limits to Airborne Contaminants (PELs) [Ref 4]. Because of court challenges and an administration adverse to new regulatory initiatives, 376 updated standards relating to airborne contaminant exposure limits were voided, and reverted to earlier, less protective levels. The numerical majority of standards have remained unchanged since the 1971 adaptation of the consensus standards published by the American Conference of Governmental Industrial Hygienists in 1969. As cited on the OSHA website [Ref 5]:

OSHA continues to believe that many of the old limits, which it will now be enforcing, are out of date (they predate 1968) and not sufficiently protective of employee health based on current scientific information and expert recommendations. In addition, many of the substances for which OSHA has no PELs, present serious health hazards to employees.

OSHA standards for a number of materials critically important to defense applications are presently being evaluated within the present regulatory process that takes many years to produce updated criteria. These include cadmium, chromium and beryllium, all products vital to defense technology products. The regulatory inactivity and inadequate response of OSHA in addressing beryllium disease and promulgating updated standards was reported in Business Week [Ref 6]. OSHA has been trying since the 1970s to lower the PEL for beryllium, currently at 2 ug/m^3. Brush Wellman, the sole U.S. beryllium refiner, utilizes an internal standard that is one tenth of the OSHA PEL. Even OSHA's prospective ability to cite ACGIH TLVs under the general duty clause is under attack by an industry coalition [Ref 7].

Some well-recognized hazardous materials have been regulated effectively to reduce exposure levels accompanied by detailed regulations that provide industry standards of practices. Asbestos is probably the best recognized such contaminant. Table 1 summarizes the reduction in allowable exposure levels. These regulations were initially regarded as difficult or infeasible to comply with and overly expensive. Present practice shows that few responsible contractors exceed the allowable exposure limits during asbestos removal unless unexpected conditions develop.

Table 1: OSHA Asbestos Limits (Summary Information)

Date	8 hour allowable time weighted average (fibers/cc)	Short Term Exposure Limit (fibers/cc)
May 29, 1971	12	
December 7, 1971 (Emergency Temporary Standard)	5	10
1972	5	10
1976	2	5
1982	1	
1986	0.2 (0.1 Action Level)	1 (30 minutes)
1988	0.2	1 (30 minutes)

A designer using current OSHA criteria to identify "safe" or acceptable exposure standards for a given contaminant for maintenance of a system intended to last 30 years would generally find that regulatory compliance would not provide a good measure of risk control. Application of more current consensus standards such as those of the American Conference of Governmental Industrial Hygienists [Ref 8] would typically be more prudent.

Many initial OSHA standards, developed to meet a deadline imposed by the OSHA Act (1970), simply reiterated then-current ANSI standards. Many of these have gradually been eliminated, streamlined or updated. The most suitable approach to design facilities and related support equipment is reference relevant to current consensus standards and practices. OSHA and related state inspectors are prone to disregard or give ***de minimus*** [1]citations for application of updated criteria that post-date regulatory standards.

Because of its regulatory mandate, OSHA is often stereotyped as being focused upon strict design, protective equipment or behavioral compliance with its regulations. This suggests a lack of process approach and absence of prioritized focus upon risk severity. However, a number of prominent OSHA regulations specifically require process evaluation and hazard management. Unlike system safety associated with system design, most are focused on ensuring compliance in existing facilities. However, the process for hazard evaluation and management is generally similar to that of system safety. Most of the newer standards include process review, development of a written program, evaluation of the work environment, medical monitoring for exposed workers, training and periodic program evaluation. Unfortunately, OSHA inspections do not monitor the system or facility design process.

OSHA process standards relevant to systems acquisition and/or system safety in facilities include:

The OSHA Process Safety Standard (29 CFR 1910.119 - Process safety management of highly hazardous chemicals [Ref 9] establishes requirements for process evaluation and management of manufacturing processes using, storing or processing certain hazardous chemicals above threshold quantities. Significantly, the standard and associated guidance documents do not reference system safety as a discipline, or cite Military Standard 882. The standard does describe use of many tools common to system safety evaluation such as FEMCA and process flow descriptions.

Standards for management of hazards associated with entry of confined spaces [Ref 10] (29 CFR 1910.146 - Permit-required confined spaces) are relevant to planning for platforms such as ships and aircraft (wing tanks) that may have confined spaces requiring periodic entry and to associated support facilities.

Safety for work at elevated locations (fall protection) is addressed in several industry-specific standards. Falls from height are the second most common source of occupational fatalities, and work at elevated locations is common to many defense systems including ships, aircraft, certain large vehicles and all associated support facilities. The issue was addressed in a previous presentation to the System Safety Society [Ref 11] and is summarized later in this paper.

Procedures for control of energy sources (lock-out/tag-out) are required during maintenance [Ref 12]. Although the system safety process is not cited in the OSHA regulations or ANSI standard [Ref 13], process management requirements including hazard characterization, procedures and physical controls for energy sources and written program management are consistent with the philosophy of system safety. The ANSI standard specifically characterizes responsibilities of manufactures and integrators (designers and developers) in design of equipment and systems to support safe and efficient energy control. Use of a systems engineering process for new designs and application of the order of precedence for control of hazards predicates consideration of design for lock-out (physical) rather than tag-out (administrative) for system safety professionals associated with designs of new and modified systems with hazardous energy sources requiring periodic maintenance. Application of system safety to control of hazardous energy was reviewed in the Journal of the System Safety Society. [Ref 14].

The OSHA laboratory safety standard [Ref 15] requires process management for chemical materials used within laboratories. It is very important to planning for R&D activities and has many requirements and guidelines that closely parallel the system safety process of Military Standard 882, but does not reference this approach.

OSHA Regulatory and Advisory Guidance for Control of Chemical Exposures

Substance-specific standards relevant to planning for life-cycle risk management include regulation of Lead [Ref 16] and Cadmium [Ref 17]. Use of these and certain other materials (probably including chromium in the near future) requires planning for stringent controls, regulated and atmospheric controlled work areas for maintenance processes,

[1] Minor regulatory violation noted without penalty.

and environmental and personnel medical monitoring that can add to the life-cycle cost and risk. Disposal of hazardous wastes can also create significant additional costs and risks. An Army study estimated that 80% of Army (and probably similar proportions of DOD) hazardous material usage and associated waste generation is associated with maintenance and sustainment of defense systems and related supporting facilities [Ref 18].

DOD acquisition regulations require planning life-cycle management including provision for support equipment and facilities and design considering human systems engineering [Ref 19][2]**.** The OSHA Process Safety Standard [Ref 9] requires hazard identification, process mapping, and a comprehensive risk management process for chemical industries involved in storage and processing of specified hazardous chemicals above certain thresholds set in relation to the risk posed by the materials. The process required is consistent with system safety practice, but does not reference Military Standard 882.

EPA – The Other OSHA

The Environmental Protection Agency has often stepped into the regulatory void left by OSHA's inability to promulgate standards promptly. An article, appropriately titled ***EPA's Intervention into Workplace Health and Safety – The Other OSHA,*** [Ref 20] details EPA's role in setting standards with overlapping impact on environmental and occupational chemical risk management. Relevance of EPA's standard setting role to system safety evaluation includes process management requirements incorporated into certain EPA standards and the much greater powers of this agency in terms of monetary penalties, and regulation of chemicals in commerce, as well as the increasing need to provide for environmental compliance. The Toxic Substance Control Act (TSCA) [Ref 21] regulates introduction of new chemical substances and Superfund Amendment Reauthorization Act, Title III [Ref 22] provides for reporting and regulation of chemical emissions. Specific regulations stimulated or directed by EPA requirements include the OSHA Process Safety Standard for Highly Hazardous Chemicals [Ref 9] and the standard for worker protection during response to hazardous material incidents [Ref 23]. (See **The Plain English Guide to the Clean Air Act**). EPA regulations associated with the Clean Air Act [Ref 24] are also critical to regulation of work practices for asbestos management and are used concurrently with OSHA Asbestos regulations [Ref 25] to manage workplace safety.

EPA has also taken the technical lead in pollution prevention, the elimination of chemical risks through substitution of less hazardous materials and processes. Many individual service and DOD efforts are also focused on reduction of chemical usage and waste generation, with a primary focus on control of environmental contamination. (See http://www.epa.gov/p2/ and http://www.epa.gov/wastemin/).

Comparing "Industrial Safety" and System Safety

The Air Force System Safety Handbook [Ref 2] provides a detailed comparison of system safety and industrial safety, partially reproduced in Table 2:

[2] DODI 5000.2 Operation of the Defense Acquisition System May 12, 2003 Paragraph 3.9.2 Sustainment Effective sustainment of weapon systems begins with the design and development of reliable and maintainable systems through the continuous application of a robust systems engineering methodology. As a part of this process, the PM shall employ human factors engineering to design systems that require minimal manpower; provide effective training; can be operated and maintained by users; and are suitable (habitable and safe with minimal environmental and occupational health hazards) and survivable (for both the crew and equipment).

Table 2: System Safety versus Industrial Safety[3]

General Concerns	
System Safety	Industrial Safety
Safety of product to include design, test, operation, maintenance and support; assembly; modifications, ultimate disposal	Safety and health of contractor employees and contractor property, work environment and general (external) environment
Operations	
Assure safety in operations of deliverable product by customer and contractor personnel	Assure potentially hazardous operations are identified and controlled under normal and foreseeable emergency situations
Equipment	
Protection of equipment including durability during use and avoidance of failures that jeopardize equipment, users or maintainers	Ensure proper hazard awareness and procedures during use and handling
Identify hazardous characteristics, HAZMAT during test, assembly, maintenance and use. Provide procedures to protect personnel and equipment from damage	Protect equipment, identify protective equipment requirements and limit or avoid product liability. Provide feedback for better ways to protect sensitive equipment and prevent injury
Facilities	
Ensure design of new facilities to meet safety requirements and existing facilities incorporate appropriate safety features.	Assure compliance with requirements for protection of personnel property and the environment.
Procedures	
Include appropriate warning and precautions for safe use	Include appropriate warning and precautions for safe use and provide appropriate training and compliance enforcement.
Personnel	
Identify potential personnel contributions to risk and mishap and communicate hazardous characteristics to industrial safety personnel	Identify training/qualification requirements and provide feedback to system safety personnel.
Changes/Unplanned Events/Mishaps	
Insure that potential safety issues are identified and addressed during changes and that design of safety is not degraded.	Access impact on safety of support/facilities personnel and the environment.
Evaluate mishaps, correct causes as possible and provide feedback to industrial safety	Evaluate mishaps, correct causes as possible and provide feedback to designers and system safety personnel. Provide guidance to better control mishap risk.

Streamlining Acquisition while Integrating OSH and System Safety Efforts - Smarter or Dumber?

Streamlining of the defense acquisition process has lead to removal of many existing standards, guidelines and requirements. Concerns for the effect of this process were expressed in an editorial in the Journal of System Safety [Ref 26]. This and other reviews express concern that lumping environment, occupational health and safety with system safety has the potential to dilute the disciplined review process provided by system safety, jeopardize the level of expertise required by program practitioners, and even refocus safety and environmental efforts into design for regulatory compliance rather than systematic risk management.

Concurrently, the acquisition workforce is facing a loss of experienced personnel and institutional knowledge posed by retirements and downsizing in many areas. The System Safety Society and G-48 Committee have been leaders in addressing the issue of system safety, but have not always been successful in this regard. A letter from the G-48 Committee to the Undersecretary of Defense for Acquisition Technology and Logistics [Ref 27], expressing

[3] Abstracted from the Air Force System Safety Manual (2000), page 115, figure 15-1

concerns about the needs for a robust system safety process and diminution of requirements in the then-current DOD acquisition criteria, [DODD 5000.2R, Ref 28] never even received a formal response.

Recent updates of the Defense Acquisition Requirements [DODI 5000.2, Ref 18] have consolidated system safety under the general section (Enclosure 7) addressing human systems integration (manpower, personnel, training and interaction of users with systems and equipment). System safety was not addressed as a distinct discipline. Limited personal participation in the process that provided input and review suggests that the discipline of system safety was inconsistently represented and that the overall summary document represented a compromise agglomerating inputs from many disciplines. System safety is required for acquisition programs and criteria for risk acceptance at levels of management consistent with the hazard are mandated. Additional guidance has been developed for the DOD Defense Acquisition Guidebook (http://akss.dau.mil/dag/) with background information on system safety.

A Secretary of Defense initiative to reduce mishaps by 50% was accompanied by initiation of a Flag-level Department of Defense Safety Oversight Committee (DSOC) with nine task forces including one addressing acquisition and technology [Ref 29]. (See https://acc.dau.mil/simplify)

On September 23, 2004, The Undersecretary of Defense for Acquisition Technology and Logistics, USD (AT&L) signed a memo [Ref 30] directing:

- Project Managers (PMs), regardless of ACAT, integrate system safety risk management into overall SE and risk management processes
- PMs use the government and industry Standard Practice for System Safety, MIL-STD-882D, in all developmental and sustaining engineering activities
- PMs ensure DODI 5000.2 requirement to integrate Environment Safety and Occupational Health (ESOH) risk management strategy into the Systems Engineering (SE) process is incorporated in the Systems Engineering Plan (SEP).
- PMs identify ESOH hazards, assess risks, mitigate the risks to acceptable levels, and then report on status of residual risk acceptance decisions at technical reviews and at the appropriate management levels in Program Review process

Past support for life cycle management and sustainment of defense systems has been inconsistent. Concurrently, there is a strong emphasis on reinvigorating the systems engineering process within DOD. A USD AT&L policy memorandum in February 2004 [Ref 31] stresses this need and places specific requirements on programs for systems engineering management. An anticipated update to the primary acquisition instruction, DODI 5000.2 will have a new section (Enclosure 10, Systems Engineering) summarizing the mandate for system engineering programs and, is also anticipated to incorporate requirements of the policy memo on system safety.

Application of the system safety discipline to diverse hazard management processes has been a theme of many practioners [Refs. 2, 31] and is reflected in the increasingly broad range of topics addressed at the System Safety Conference including chemical safety management, control of physical agent hazards, ergonomics and software safety.

The regulatory approach imposed upon practitioners within DOD appears to create the need to communicate the advantages that the discipline of system safety conveys to the acquisition community in the context of systems engineering, risk management and life-cycle control of a range of hazards. This should not mean adapting a approach limited by existing regulations, which often lag well behind current technical knowledge and do not generally contain a format suitable for providing focused attention by relative risk.

The above policy directives support increased attention to system safety and create a venue to addressing many occupational safety and environmental risks. They don't provide a clear understanding of the approaches used by each discipline. Nor do they automatically create necessary funding, manpower or effective review process to enforce their intent.

Where's the User? Ergonomics and Human Systems Integration

Ergonomic injuries are the fastest growing category of occupational injuries and illness. OSHA [Ref 33] estimated direct costs of $15 billion annually with indirect costs increasing this total to the range of $45 billion. Application of human engineering principles in design and modeling to ensure effective user interface markedly increases efficiency and reduces risk and injury to users. Proactive design approach and early identification of potential risk factors should be integrated into the systems engineering process. Management of identified risk factors such as material handling, potential entry into restricted locations, and repetitive motion can be potentially related to specific process, work tasks and designs inconsistent with known human engineering criteria. System safety offers the most effective approach to management of risks related to design interface when such factors can be related to a risk and severity matrix.

OSHA attempts to develop an ergonomic standard were overturned by Congress with significant pressure from industry in March 2000, [Ref 33]. This was despite documentation associated with the failed OSHA Ergonomics Standard [Ref 34] that demonstrated significant economic advantages to those organization implementing ergonomics programs, in addition to reduction of worker injuries and lost time. Review by Biddle and Roberts [Ref 33] substantiated OSHA's fiscal estimates and supported the documented societal and business impacts of musculoskeletal injuries.

DOD agencies maintain active ergonomics programs, which are supported on the basis of conserving productivity while improving efficiency. For example, the Navy Occupational Safety and Health Program Manual [Ref 35] describe requirements and provides program guidance for local ergonomic programs. A program for documentation and publication of "success stories" describes a number of technical and managerial approaches that have yielded significant fiscal and productivity benefits while reducing or eliminating injuries. (See www.safetycenter.navy.mil/successstories). About half of these are retrofits involving ergonomic improvements. Many have return on investments exceeding 5:1.

DOD emphasis on manpower reduction and labor force management is reflected in DODI 5000.2 requirements for human systems integration (HSI) programs including manpower, training and human engineering associated with major acquisition programs. The cross linkage of safety and environment within the HSI requirements pose both a challenge and an opportunity to integrate the disciplines of system safety with management of human factors in design.

As the complexity of systems and their interactions increase, those interactions and their control must become a subject for evaluation. Major system disasters have been linked to poor design of controls and displays as well as design induced errors in human responses. Application of human factors engineering in design can reduce lost or misapplied labor efforts and related risk of injuries associated with material handling, maintenance and repetitive tasks, such as computer use and certain maintenance or assembly operations. Guidance for design is available in sources such as Military Handbook 1472 and ASTM F1166 [Refs. 36 and 37]. Guidance for top-down evaluation of work requirements and related evaluation and task design is available in DOD Handbook 763 and Mil Std 1337 [Refs. 38 and 39]. The Chief of Naval Operations acquisition safety liaison office has developed general information and examples of the application of safety and health controls within the acquisition process. Information on ergonomic issues associated primarily with ship design is available at www.safetycenter.navy.mil/acquisition).

Control of Hazards Associated with Elevated Work Locations

Falls from height (generally above 6 feet) are the second leading cause of occupational fatalities, and account for approximately 700 occupational fatalities annually in the United States (Bureau of Labor Statistics, BLS, (2003). (Traffic-related fatalities remain the leading cause of occupational deaths in the United States). The number of such fatalities has continued to rise over the past decade while most work-related injuries are declining in number. Total fall injuries recorded in U. S. private industry have declined with regulatory attention from 374,831 in 1992 to 288,500 in 2001. However, the average number of fatalities has risen from 479 in 1992 to 607 in 2002. Approximately half of these deaths occur in the construction industry. The general reduction in fall injuries is likely to be related to regulatory requirements and their more stringent enforcement. OSHA (1998) reported that 150 to 200 workers are killed annually, in the construction industry while, 100,000 are seriously injured as a result of falls from height.

Protection against falling from heights during operations conducted at elevation is one of the more intuitively clear safety requirements. The regulatory definition of an *elevated work location* varies by industry from four (4) to fifteen (15) feet[4]. OSHA regulations and consensus standards (ANSI Z359) stipulate *assured fall protection* for elevated work locations that provides a fixed barrier or use an approved personal fall arrest system. An *assured fall protection system* is defined as a combination of equipment and work practice that either prevents falls by measures such as fixed barriers (preferred) or alternatively fall arrest systems. The later provides a means to arrest and reduce the impact of a fall through a *personal fall arrest system*. [5]

Application of System Safety Principles to Control Fall Hazards in Design of Ships and Facilities

Application of system safety principles to facility and shipboard confined spaces and elevated work locations provides the following order of precedence for hazard mitigation: *

1. Hazard Elimination

Design and maintain to avoid or minimize the need for access to hazardous locations by measures such as:
- Design for retractable or movable systems that allow servicing from ground level, such a street lamps that are designed with hinged bases that allow the bulb to be serviced from street level.
-Long life paint systems
-Isolated tanks not needing routine painting
- Location of controls and sensors outside the tank where feasible.

2. Fixed Barriers - Where Feasible

Fixed barriers include permanent railing and temporary barriers around manholes and railings on scaffolding erected inside tanks prior to major work such as blasting and painting.

3. Hazard Mitigation via Design for Safe and Efficient Access - stressing application of human factors engineering criteria

-Access ports
-Ladders (include safety rails)
-Appropriate location of anchor points for scaffolding and fall arrest systems*.
*Initial access and inspection is often the most difficult task

4. Procedures and Warnings: Evaluation of Special Hazard Areas

-Redundant fall arrest (ladders may be corroded).
-Preliminary and ongoing purging and atmospheric testing
-Consideration of emergency rescue in planning and procedures

5. Protective Equipment (and related training and enforcement).

Design engineers should support the effective application of this measure by
- Design to provide appropriately placed anchor points for fall arrest systems and scaffolding
- Design for safe access to elevated work locations.

**Some control measures are overlapping and concurrently applied such as design of effective anchorage for fall protection harnesses and procedures involving use of this protective equipment.*

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[4]OSHA Regulatory requirements by industry are five (5) feet for shipyard employment (29 CFR 1915.159 and 29 CFR 1915.77c); six (6) feet for construction (29 CFR 1926.501 (b); and four (4) feet for General Industry (29 CFR 1910.23 b); fifteen (15) feet for Steel Erection (29 CFR 1926.760 (a)); (29 CFR 1926.Subpart R 1926.750 to 760); eight (8) feet for Marine Terminals and Longshoring, 29 CFR 1918. (See http://www.osha.gov/ for regulations).

[5] A personal fall arrest system includes an approved full body harness, device(s) designed to provide controlled expansion that limits the impact forces created by the fall on the victim (to 1800 pounds) and an assured anchorage point (3600 lbs). The device providing controlled deceleration may include a lanyard, deceleration device, lifeline, or suitable combinations of these. The use of body belts for fall arrest has been prohibited since January 1, 1998.

The Naval Facilities Engineering Command's Fall Protection Guide [Ref 40] references documentation that costs for implementation of fall protection measures increases by a factor of ten for each stage of incorporation from consideration in the initial design ($1x); to post configuration of major structures in preliminary design ($10x); to construction ($100x); to ultimate use during maintenance ($1000x).

As an example, entry into deep storage tanks on aircraft carriers is both hazardous and difficult because of the space configuration and the limited dimensions of access pathways. Major risks include potential falls of up to 50 feet, entrapment in confined spaces and atmospheric hazards. Necessary precautions contribute significantly to life-cycle maintenance costs. Design alternatives were reviewed by application of human engineering criteria and process flow evaluation. Minor configuration changes were suggested for new vessels. It is estimated that application of these guidelines could enhance the safety and efficiency of entry while reducing maintenance costs by approximately 35%, or in the range of $250,000 per shipyard availability period. Implementation costs are estimated to be relatively low for new construction [Ref 41]. A summary of relevant guidelines for vessel inspection was developed for consideration by the American Bureau of Shipping [Ref 42].

Protective Equipment – Not So Easy to Implement - Not So Protective

The order of precedence in Military Standard 882, and virtually all occupational safety and health guidance, requires that substitution of less hazardous processes and materials and engineering controls for residual hazards be considered as the first and optimal measures to reduce safety risks. Procedures, training and protective equipment are considered the less effective alternatives, to be used where engineering controls are not practical or fully protective. The limitations associated with protective equipment and the administrative burden their use imposes, are consistently underestimated.

OSHA standards for protective equipment [Ref 43], respiratory protection [Ref 44] and hearing conservation [Ref 45] specifically require consideration of alternatives to protective equipment use; development of written programs; process review; identification of alternative control measures; clear specification of required protective equipment; ensuring compliance with relevant design (typically ANSI or NIOSH) standards and testing; associated training; medical evaluation (for users of hearing protection and respiratory protection); equipment inspection and periodic program review.

The hearing conservation standard imposes detailed requirements for estimating the actual effectiveness of hearing protective equipment. For example, when no detailed data is available, the least involved approach requires that 7 dB be deducted from the Noise Reduction Rating (NRR) associated with the specific protective equipment used. In practice, hearing protection often provides even less effective protection. Evaluation of hearing protection use of aircraft carrier decks demonstrated that fully half (47%) of personnel were not using double hearing protection despite noise levels well above the level that double protection provides. Use of gloves or other equipment for skin protection requires matching the properties of resistance to solvent penetration and permeation to the equipment used. This requirement is generally not well understood and effective compliance in complex industrial settings is the exception. Other standards such as those for lead, asbestos, cadmium, hazardous material response and laboratory safety require stringent programs for use and evaluation of protective equipment [Refs 14, 15, 16, and 25]. As readily anticipated, the level of compliance with protective equipment usage varies greatly and the level of effective protection afforded is often poor. Thus use of protective equipment imposes an unrecognized life cycle cost for system support that includes training, medical monitoring, equipment and management overview while providing a variable level of actual protection.

Risk Identification- Development of a Preliminary Hazard List

Preliminary hazard lists and subsequent analysis should include many commonly regulated "OSH" factors as appropriate to the system and support equipment and facilities including, but not limited to: noise; vibration; electrical and mechanical energy control during servicing (lock-out/tag-out); hazards of falls from elevated work locations and an assessment of chemical risks based on up-to-date hazard information. A summary of "OSH" risks associated with ship designs was communicated to the DDx (new destroyer) program and may serve as a model for related Preliminary Hazard Lists (PHLs), [Ref 43]. Hazard evaluation should be based on identification of underlying risk. Regulatory criteria and associated standards should be used as design guidance and thresholds for facility compliance rather than definitive measures of safety. Consideration of these risks and design to control common hazards will result in safer and more efficient systems and equipment. Neglect of such factors will engender the creation of life-cycle risks; potentially require retrofits, and may even impact cost, safety and efficiency of initial production.

Summary

The regulatory approach often associated with OSHA enforcement and many occupational health and safety programs has tended to describe measures that must be taken in existing facilities and equipment. It has often been applied in a manner stressing procedural and design compliance without consistent identification of relative risk. Additionally, there has often been a misunderstanding and related over-estimation of the effectiveness and economy of using protective equipment to manage potential exposures. The continued incidence of hearing loss despite aggressive DOD hearing conservation programs demonstrates the limitations of primary reliance on protective equipment for risk management. Use of personal fall arrest systems and respiratory protection, among other measures; has demonstrated similar inconsistencies in effectiveness and many incompletely documented costs. Use of protective equipment as the main approach to hazard management is inconsistent with the hierarchy of controls applied by system safety and good systems engineering practice. Primary reliance on protective equipment for hazard mitigation is also nominally inconsistent with regulatory requirements. However, the likelihood of receiving a significant violation on the basis of this approach is minimal.

Application of risk-based system safety versus regulatory compliance approaches provides the most effective method for early identification of critical occupational safety hazards in system design. Identification of risk in the Preliminary Hazard List (PHL), management as part of the design process and mitigation through the conventional hierarchy of controls provides the most cost-effective methodology for hazard management. The existence of potential hazards and technological risks should not be delineated by regulatory compliance. Instead, reference to regulatory or guidance criteria may be used as an indication or threshold for including a specific physical agent or chemical agent in the PHL.

Work at elevated locations poses a fairly obvious risk of injury from falling to a lower level that should be considered in development of the PHL. Potentially affected systems include facilities, ships, aircraft (maintenance operations), communication towers and certain large vehicles. The severity of this risk is clearly related to the potential fall distance and type of surface below. The regulatory threshold for implementation of “fall protection” programs varies with industry between four (4) and fifteen (15) feet and represents a “legal compromise” between technical feasibility, cost and human risk. These criteria may also be influenced by the relative strength and effectiveness of varied stakeholders. They clearly do not represent a fine line between “safe and unsafe”. Therefore, an initial risk-based evaluation must be based on hazard identification. Final engineering control measures need to provide for regulatory compliance within the context of good design.

There is a concurrent DOD and Navy focus upon strengthening system engineering and the application of human engineering and human systems integration during the acquisition process. Combining these approaches provides a methodology to ensure design for users and coordination of developmental efforts. The result should be lowered life-cycle costs and risks associated with improved process description, risk evaluation, hazard management and operational controls.

As an example, entry into deep storage tanks on existing aircraft carriers is both hazardous and difficult because of the space configuration and the limited dimensions of access pathways. Design alternatives were reviewed by application of human engineering criteria and process flow evaluation. Minor configuration changes were suggested for new vessels. It is estimated that application of these guidelines could enhance the safety and efficiency of entry while reducing maintenance costs by approximately 35%, or in the range of $250,000 per shipyard availability period. Implementation costs are estimated to be relatively low for new construction.

The Chief of Naval Operations, CNO Safety Liaison Office (Code N09FB) has worked to ensure management of commonly understood risks through enhancing the risk management requirements in acquisition capabilities documents. We have also developed eTools and related website information for communication of common categories of occupational safety hazards in format and language relevant to acquisition, including discussion of case studies. It is anticipated that these efforts, identification of occupational safety risks in the PHL, and their risk-based evaluation in the hazard matrix of Military Standard 882 will support improved cost and risk management.

Consideration of human factors engineering – design to fit users- and review of "conventional" safety and health issues in the system safety process supports design of new military systems with enhanced safety, economy and efficiency over the products life cycle.

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